CHAPTER 8

ENERGY REQUIREMENTS AND CONSERVATION

8.1 Introduction

Land treatment systems energy needs consist of preapplication treatment, transmission to the application site, distribution pumping (if necessary), and tailwater recovery or pumped drainage (if required). The energy required for preapplication treatment varies considerably depending on the degree of treatment planned. The degree of treatment depends on type of system, local conditions, and regulatory requirements. Determining energy requirements for all preapplication treatment systems is beyond the scope of this manual; however, equations for estimating, energy consumption of minimum preapplication unit processes are presented in Section 8.6. Energy required for construction is too site-specific to be included in this manual.

Energy for transmission from the preapplication treatment site to the land treatment site depends on topography and distance. This is especially important when considering alternative sites. The energy required for transmission pumping can range anywhere from zero to nearly 100% of the energy requirements for a land treatment system. This may often justify a higher priced parcel of land closer to the application site. Transmission pumping is sometimes designed to also provide pressure for sprinkler application. For sites located below preapplication treatment facilities with surface application systems, pumping usually will not be required.

Slow rate systems vary in terms of distribution energy and possible tailwater control. Distribution systems may be surface or sprinkler. Tailwater control requirements depend on the type of distribution system and discharge standards. Sprinkler systems can be controlled so that no tailwater is produced. Surface systems will usually have tailwater that must be contained and reapplied.

Rapid infiltration systems are usually designed for surface distribution and application and so require minimal energy. There is no tailwater pumping, but pumped drainage may be necessary to control ground water levels or recover treated percolate.

Overland flow systems can use surface distribution with low head requirements (Section 6.6.1). Sprinkler systems can also be used so energy will be required for pressurization. There is no significant subsurface drainage with OF so this potential energy requirement is avoided.

8.2 Transmission Pumping

Under conditions with favorable topography, a gravity transmission system may be possible and pumping not required. If pumping is required, the energy needs vary substantially depending on the required head and how the transmission system is designed. The effect of topography on pumping costs and energy use should be thoroughly evaluated during the planning process.

Energy efficient design involves coordination of all elements of the system including sizing of pumps, pipelines, and storage facilities, as well as system operating strategy. The system operating strategy involves placement and sizing of storage facilities. Wet wells are typically not designed for significant flow equalization. Transmission pumping systems are sized to handle the peak community flows. This can be accomplished by multiple pumps, one pump with a variable speed drive, or some combination. Each system has differing constraints that alter decisions on its design. Ideally, all flow is equalized to provide nearly constant flow pumping. This allows selection of a pump at a maximum efficiency.

Variable speed drives, which are not as efficient as constant speed drives, would not be required. Unfortunately, flow equalization is not always feasible. In some instances, equalization costs may not be recovered by energy savings. The choice of pumping and equalization system design is site-specific. Regardless of the pumping system used, pipeline size can be optimized. Optimization of pipeline size will provide the optimum transmission system.

The following pipe size optimization procedure was taken from reference [1] . Obviously, larger pipe sizes result in lower pumping energy; however, excessively large pipes are not economical.

$$D_{opt} = AQ^{0.486}C^{-0.316}(KT/PE)^{0.17} \tag{8-1}$$

where D_{opt} = optimum pipeline diameter, m (ft)

A = constant, 3.53 (2.92)

Q = average flow, m^3/s (ft^3/s)

C = Hazen-Williams coefficient

K = average price of electricity, \$/kWh

T = design life, yr

P = unit cost of pipe, \$/linear m·mm dia. (\$/linear ft·in. dia.)

E = overall pumping system efficiency, decimal

For example, at a flow of 0.219 m^3/s (7.7 ft^3/s), a Hazen-Williams coefficient of 100, a pipeline cost of \$0.26/linear m·mm diameter, an overall pumping system efficiency of 75%, electricity at \$0.045/kWh, and a design life of 20 years, the optimum pipe diameter is 0.50 m (20 in.) [2].

With the line size determined and a pumping system selected, the actual energy requirement can be determined by the following equation.

$$\text{Energy, kWh/yr} = \frac{(Q)(TDH)(t)}{(F)(E)} \tag{8-2}$$

where Q = flow, L/min (gal/min)

TDH = total dynamic head, m (ft)

t = pumping time, h/yr

F = constant, 6,123 (3,960)

E = overall pumping system efficiency, decimal

The overall efficiency varies not only with design specifics but also with the quality of liquid being pumped. Raw wastewater pumping requires pumps that pass larger solids than treated effluent. These pumps are less efficient. When a specific design is being contemplated, the overall efficiency should be determined using pump, motor, and driver efficiencies determined for the equipment to be used. For initial planning or preliminary work such as site selection, overall system efficiencies can be assumed as follows.

Raw wastewater	40%
Primary effluent	65%
Secondary or better effluent, tailwater, recovered ground water, or stormwater	75%

8.3 General Process Energy Requirements

8.3.1 Slow Rate

Energy consumption for SR consists of transmission, distribution, possible tailwater reapplication, and crop management. A wide range of surface and sprinkler distribution techniques is possible. Surface systems require energy for distribution and tailwater reapplication to the site. Sprinkler systems are highly variable with possible pressure requirements ranging from 10 to 70 m (30 to 230 ft). Generally, pressures will be in the 15 to 30 m (50 to 100 ft) range.

Crop production energy varies substantially between the type of crops grown. Table 8-1 shows energy requirements for corn and forage crops.

TABLE 8-1
ENERGY REQUIREMENTS FOR
CROP PRODUCTION [3]

Operation	Requirement, MJ/ha	
	Corn	Alfalfa
Tillage and seeding	1.41	0.22
Cultivation	0.37	NA
Herbicide/insecticide	0.37	0.37
Harvest	0.37	1.51[a]
Drying	4.69[b]	NA[c]
Transportation	1.04	1.53
Total	8.25	3.63

a. Hay.

b. Mechanically dried; may in some cases be field dried.

c. Not applicable, field dried.

8.3.2 Rapid Infiltration

Rapid infiltration system energy requirements are primarily those needed for transmission. Surface distribution is normally used. There are no crops grown so no fuel is consumed for that purpose. Occasionally, there are situations where recovery wells and pumps are used. Fuel will be needed for basin scarification, but the quantity is not significant because the operation is infrequent.

8.3.3 Overland Flow

Overland flow treatment can use either surface distribution or sprinkler distribution. Surface distribution requires minimal energy (see Section 8.6), while sprinkler distribution requires pressurization energy.

To prevent nozzle clogging, raw wastewater or primary effluent should be screened prior to distribution. Mechanically cleaned screens are preferred over comminution since shredded material returned to the stream can still cause clogging. The amount of energy required for screening is insignificant compared to the pumping energy required. Equation 8-2 applies for the pumping energy computation.

Overland flow systems require a cover crop that is often harvested and removed from the site. Energy is required in the form of diesel fuel for operating harvesting equipment. Fuel required is the same as presented in Table 8-1 for alfalfa harvest.

A summary of energy requirements for land treatment processes is shown on Table 8-2. The values presented are typical of actual practice.

TABLE 8-2
MOST COMMON UNIT ENERGY REQUIREMENTS FOR LAND TREATMENT OF MUNICIPAL WASTEWATER

Treatment system	Component	Electricity, kWh/1,000 m^3	Fuel, MJ/1,000 m^3	Total equivalent, kWh/1,000 m^3
Slow rate	Pumping for distribution	0.14	--	0.14
	Crop planting, cultivation, harvest, drying, transport	--	0.68	0.20
	Energy credit for fertilizer value of wastewater	--	(0.50)	(0.14)
Total		0.14	0.18	0.20
Rapid infiltration	Distribution (gravity)	--	--	--
	Recovery wells	0.05	--	0.05
Total		0.05	--	0.05
Overland flow	Transmission	0.10	--	0.10
	Forage harvest	--	0.22	0.06
Total		0.10	0.22	0.06

Note: See Appendix G for metric conversions; kWh are used for electricity and total equivalent energy, MJ used for fuel.

8.4 Energy Conservation

8.4.1 Areas of Potential Energy Savings

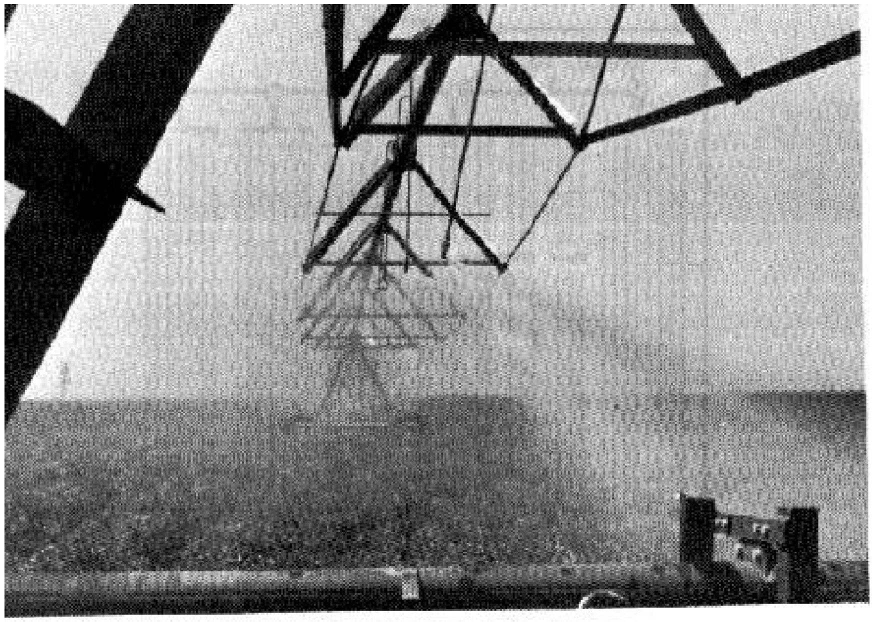
With respect to energy conservation, there are two main areas to review. First is transmission to the site. Location of the facility should, if possible, provide for adequate drop in elevation between the preapplication treatment and the land treatment sites. This layout is sometimes possible with RI systems and certain SR systems. It is more difficult to design OF systems in this manner since sloping land is necessary as part of the process. For OF systems, site grading is usually required to obtain desired slope so distribution pumping is typically necessary.

The second area of potential energy savings is with the distribution method. For domestic wastewater with minimal preapplication treatment, surface systems are preferred, since surface systems are not as subject to clogging and usually require less energy.

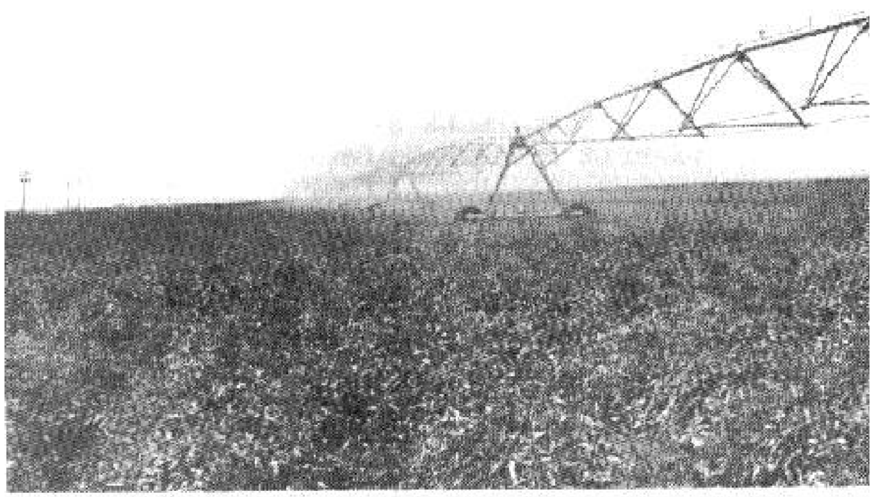
Distribution for SR systems is a function of topography and the crop. Surface systems can be used on level or graded sites (see Section 4.7.1). In the past, surface systems were preferred by the agricultural industry; however, due to increased labor costs and poor irrigation efficiencies, some existing surface systems have been converted to sprinkler irrigation. For municipal authorities where labor wages are higher than farm worker wages, the increased labor costs are important.

Sprinkler distribution systems are relatively high-pressure devices. Recent advances have been made in sprinkler nozzle design to lower headloss without sacrificing uniformity of application. Figure 8-1 illustrates a center pivot system with two types of sprinklers. The impact sprinklers have a typical pressure loss of approximately 60 to 65 m (200 to 215 ft); whereas, drop nozzles have a headloss of 15 to 20 m (50 to 65 ft). This difference represents an energy savings of about 95 kWh/1000 m3, without sacrificing distribution efficiency.

Surface systems may not require pumping energy except for tailwater recycling. In this case, automated surface systems (Figure 8-2) can be introduced to minimize tailwater recycling requirements.



DROP NOZZLE SYSTEM



IMPACT SPRINKLER SYSTEM

FIGURE 8-1
CENTER PIVOT SYSTEM

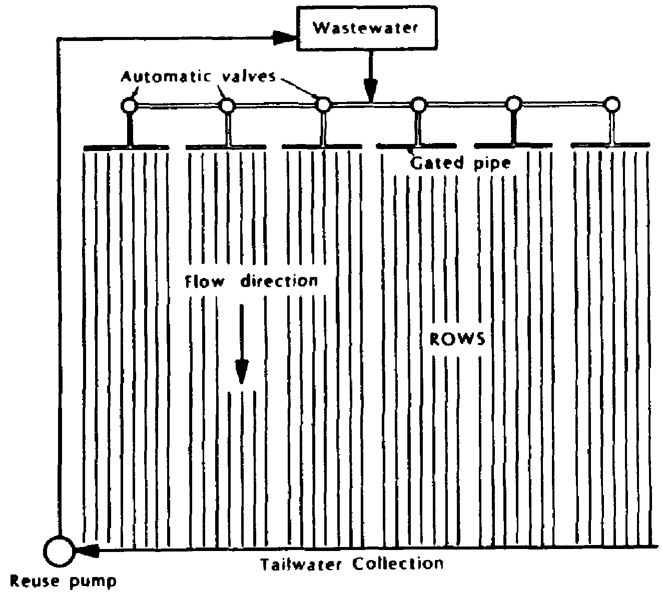


FIGURE 8-2
AUTOMATIC SURFACE IRRIGATION SYSTEM [4]

8.4.2 Example: Energy Savings in Slow Rate Design

The following example illustrates how effective planning and design can result in energy conservation. A summary of assumed system characteristics used for this example is presented in Table 8-3.

TABLE 8-3
EXAMPLE SYSTEM CHARACTERISTICS

Average flow, m^3/d	38,000
System	Slow rate
Preapplication treatment	Pond
Application season	May to October (5 months)
Hydraulic loading, m/yr	1.2
Net land area, ha	1,130
Crop	Corn
Topography	Nearly level, suitable for all types of irrigation
Tailwater control	No surface discharge of applied wastewater allowed

Three systems will be considered: surface distribution by ridge and furrow, and two examples of center-pivot application. Since transmission of wastewater is essentially the same with all alternatives, it will not be included in this discussion.

Ridge and furrow distribution does not require pumping for distribution; but due to a no discharge of tailwater requirement, energy is required to return tailwater back to the application point (assumed head: 3 meters). Depending on the system design, the maximum tailwater recycle will range from 30 to 70% of that applied. Conventional ridge and furrow designs result in lower efficiency, with the higher recycle pumping requirement. Alternatively, ridge and furrow systems with automated recycle cutback or automated valves can improve efficiency by lowering pumping requirements. The potential savings from system automation is summarized in Table 8-4.

TABLE 8-4.
COMPARISON OF CONVENTIONAL AND AUTOMATED RIDGE AND FURROW SYSTEMS FOR 38,000 m^3/d[a]

System	Tail-water pumping, kWh/yr	Electricity, $/yr	Labor, h/yr	Labor cost, $/yr	Capital cost, $	Amortized capital, $/yr	Total annual cost, $/yr
Conventional	89,300	2,950	2,800	30,800	16,000	1,520	35,270
Automated	33,500	1,100	1,400	15,400	45,000	4,300	20,800
Difference	55,800	1,850	1,400	15,400	-29,000	-2,780	14,470

a. Electricity at $0.036/kWh. Labor at 1.2 h/ha·d for automated systems; 2.5 h/ha/d for conventional systems. Labor cost at $11.00/h. Capital costs for pipeline, distribution system, reuse system meters (January 1980). Capital amortized at 7-1/8% for 20 years.

The potential savings using automated irrigation systems are significant; both energy consumption and cost can be reduced substantially. In this example, energy requirements were reduced by about two-thirds, at an overall cost savings of over 50%.

If a center pivot irrigation system is used, tailwater recovery is not needed. However, pumping energy is required to provide nozzle pressure. In this case the main factor in energy conservation is nozzle design. The general goal is to achieve uniform distribution at the lowest possible pressure loss. A conventional center pivot rig employs impact sprinklers on top of the pivot pipeline. These devices require a pumping pressure of approximately 65 m (21 ft). Alternatively, drop nozzles are used in modern rigs which develop a headloss of about 15 m (150 ft). Drop nozzles have an additional advantage of producing less aerosol than impact systems. Capital costs, and operation and maintenance requirements (except for electricity) are comparable between these two systems. The impact on energy savings is shown on Table 8-5. In this instance, costs were reduced and aerosols were decreased by designing to conserve energy.

TABLE 8-5
COMPARISON OF IMPACT AND DROP-TYPE
CENTER PIVOT SYSTEM NOZZLE DESIGNS
ON ENERGY REQUIREMENTS,
38,000 m3/day

Nozzle type	Electricity, kWh/yr	Energy cost, $/yr
Impact	2,230,000	73,600
Drop	1,030,000	34,000
Difference	1,200,000	39,600

8.4.3 Summary

For purposes of comparison the total energy (electricity plus fuel) for typical 3,785 m^3/d (1 Mgal/d) systems is listed in Table 8-6 in order of increasing energy requirements. It is quite apparent from Table 8-6 that increasing energy expenditures do not necessarily produce increasing water quality benefits. The four systems at the top of the list, requiring the least energy, produce effluents comparable to the bottom four that require the most.

8.5 Procedures for Energy Evaluations

The following section provides step-by-step procedures for computing energy use for each of the three land treatment systems. Examples are also provided. The energy computation requires site selection and a decision concerning location of preapplication and storage facilities because elevation differences for pumping are critical. The distribution method must also be determined.

TABLE 8-6
TOTAL ANNUAL ENERGY FOR TYPICAL 3,785 m^3/d
(1 Mgal/d) SYSTEM (ELECTRICAL PLUS FUEL,
EXPRESSED AS 1,000 kWh/yr) [5]

Treatment system	Effluent quality, mg/L				Energy, 1,000 kWh/yr
	BOD	SS	P	N	
Rapid infiltration (facultative pond)	5	1	2	10	150
Slow rate, ridge + furrow (facultative pond)	1	1	0.1	3	181
Overland flow (facultative pond)	5	5	5	3	226
Facultative pond + intermittent filter	15	15	--	10	241
Facultative pond + microscreens	30	30	--	15	281
Aerated pond + intermittent filter	15	15	--	20	506
Extended aeration + sludge drying	20	20	--	--	683
Extended aeration + intermittent filter	15	15	--	--	708
Trickling filter + anaerobic digestion	30	30	--	--	783
RBC + anaerobic digestion	30	30	--	--	794
Trickling filter + gravity filtration	20	10	--	--	805
Trickling filter + N removal + filter	20	10	--	5	838
Activated sludge + anaerobic digestion	20	20	--	--	889
Activated sludge + anaerobic digestion + filter	15	10	--	--	911
Activated sludge + nitrification + filter	15	10	--	--	1,051
Activated sludge + sludge incineration	20	20	--	--	1,440
Activated sludge + AWT	<10	5	<1	<1	3,809
Physical chemical advanced secondary	10	10	1	--	4,464

NOTE: RBC = rotating biological contactor.

8.5.1 Slow Rate

Step 1: Transmission Pumping

1. Elevation at site ______ m
2. Elevation at source ______ m
3. Elevation difference ______ m
4. Average annual flowrate _____ L/min
5. Pumping system efficiency _____ %
6. Pipeline diameter _____ cm
7. Pipeline length _____ m
8. Pipeline headloss _____ m
9. Total dynamic head _____ m
10. Energy requirement _____ kWh/yr (Eq. 8-2)

Step 2: Distribution Energy

1. Flowrate ______ L/min
2. Pressure head required _____ m
3. System efficiency ______ %
4. Operating time ______ h/yr
5. Pipeline headloss ______ m
6. Total dynamic head ______ m
7. Energy requirement ______ kWh/yr (Eq. 8-2)

Step 3: Tailwater Pumping (if required)

1. Flowrate _____ L/min
2. Lift required _____ m
3. Headloss _____ m
4. Assumed pumping system efficiency _____ %
5. Operating time _____ h/yr
6. Energy requirement _____ kWh/yr (Eq. 8-2)

Step 4: Crop Production (Table 8—1)

1. Tillage and seeding _____ MJ/ha·yr
2. Cultivation _____ MJ/ha·yr
3. Insecticides and herbicides _____ MJ/ha·yr
4. Harvest _____ MJ/ha·yr
5. Drying _____ MJ/ha·yr
6. Transportation _____ MJ/ha·yr
7. Crop area _____ ha
8. Total fuel requirement _____ MJ/yr

Step 5: Combine Steps 1 through 4, expressed as kWh/yr

8.5.2 Rapid Infiltration

Step 1: Transmission Pumping

1. Elevation at site ______ m
2. Elevation at source _____ m
3. Elevation difference _____ m
4. Average flow _____ L/min
5. Assumed pumping system efficiency _____ %
6. Pipeline diameter _____ cm
7. Pipeline length _____ m
8. pipeline headloss _____ m
9. Total dynamic head _____ m
10. Energy requirement _____ kWh/yr (Eq. 8-2)

Step 2: Drainage Water Control (if necessary)

1. Elevation of water source ______ m
2. Elevation of discharge _____ m
3. Difference in elevations _____ m
4. Pumping system efficiency _____ %
5. Operating hours _____ h/yr
6. Pumped flow _____ L/min
7. Energy requirement _____ kWh/yr (Eq. 8-2)

Step 3: Combine Steps 1 and 2

8.5.3 Overland Flow

Step 1: Transmission Pumping

1. Elevation at site ______ m
2. Elevation at source _____ m
3. Elevation difference _____ m
4. Average annual flow _____ L/min
5. Assumed pumping system efficiency ______ %
6. Pipeline diameter _____ cm
7. Pipeline length _____ m
8. Pipeline headloss _____ m
9. Total dynamic head _____ m
10. Energy requirement _____ kWh/yr (Eq. 8-2)

Step 2: Distribution System

1. Type of system
2. Flowrate _____ L/min
3. Pressure head required _____ m
4. Assumed pumping efficiency _____ %
5. Operating time _____ h/yr
6. Total dynamic head _____ m
7. Energy requirement _____ kWh/yr (Eq. 8-2)

Step 3: Grass Removal (Table 8-1)

1. Maintenance requirements, fuel use _____ MJ/harvest
2. Grass removal frequency _____ harvest/yr
3. Fuel for harvest _____ MJ/ha
4. Total fuel required _____ MJ/year

Step 4: Combine Steps 1 through 3, express as kWh/yr

8.5.4 Examples

Using the previously presented step-by-step procedures, the following example problems were developed.

8.5.4.1 Slow Rate

The slow rate system is designed to treat pond effluent as follows:

Average flow	15,000 L/min
Season	5 months
Applied flow	36,000 L/min
Crop grown	Corn
Distance to site	100 m
Tailwater pumping	Not required
Area	650 ha

Step 1: Transmission Pumping

1. Elevation at site 50 m
2. Elevation at source 48 m
3. Elevation difference 2 m
4. Average annual flowrate 15,000 L/min
5. Pumping system efficiency 40%
6. Pipeline diameter 76 cm
7. Pipeline length 100 m
8. Pipeline headloss 3.4 m
9. Total dynamic head 5.4 m
10. Energy requirement 289,711 kWh/yr

Step 2: Distribution Energy

1. Flowrate 36,000 L/min
2. Pressure required 10 m
3. System efficiency 75%
4. Operating time 3,600 h/yr
5. Pipeline headloss 2 m
6. Total dynamic head 12 m
7. Energy requirement 338,658 kWh/yr

Step 3: Tailwater Pumping (if required) (not required with sprinklers)

1. Flowrate _____ L/min
2. Lift required _____ m
3. Assumed pumping efficiency _____ %
4. Operating time _____ h/yr
5. Energy requirement _____ kWh/yr

Step 4: Crop production (full)

1. Tillage and seeding 1.41 MJ/ha·yr
2. Cultivation 0.37 MJ/ha·yr
3. Insecticides and herbicides 0.37 MJ/ha·yr
4. Harvest 0.37 MJ/ha·yr
5. Drying 4.69 MJ/ha·yr
6. Transportation 1.04 MJ/ha·yr
7. Crop area 650 ha
8. Total fuel requirement 5,120 MJ/yr = 1,422 kWh/yr

Step 5: Total energy use = 629,791 kWh/yr

8.5.4.2 Rapid Infiltration

The rapid infiltration system is designed to treat primary effluent as follows:

Flowrate	15,000 L/min
Distance to site	5,000 m
Drainage	pumped wells

Step 1: Transmission Pumping

1. Elevation at site 1,115 m
2. Elevation at source 1,105 m
3. Elevation difference 10 m
4. Average flow 15,000 L/min
5. Assumed pumping system efficiency 65%
6. Pipeline diameter 50 cm
7. Pipeline length 5,000 m
8. Pipeline headloss 20 m
9. Total dynamic head 30 m, operating 8,760 h/yr
10. Energy requirement 990,465 kWh/yr

Step 2: Drainage Water Control (if necessary)

1. Elevation of water source 1,105 m
2. Elevation of discharge 1,115 m
3. Difference in elevations 10 m
4. Pumping system efficiency 75%
5. Operating hours 2,920 h/yr
6. Pumped flow 10,000 L/min
7. Energy requirement 63,585 kWh/yr

Step 3: Total energy use = 1,054,050 kWh/yr

8.5.4.3 Overland Flow

An overland flow system is planned for a small community. The system will be used to treat screened raw wastewater. Design parameters are as follows:

Design flow	137 m^3/d
Distribution method	Gated pipe
Distance from source to site	100 m
Hydraulic loading	4.5 in/yr
Land area	1 ha

Step 1: Transmission Pumping

1. Elevation at site 125 m
2. Elevation at source of 120 m
3. Elevation difference 5 m
4. Average annual flow 95 L/min
5. Assumed pumping system efficiency 40%
6. Pipeline diameter 10 cm
7. Pipeline length 100 m
8. Pipeline headloss 1.22 m
9. Total dynamic head 6.22 m
10. Energy requirement 2,113 kWh/yr

Step 2: Distribution System

1. Type of system — gated pipe
2. Flowrate 95 L/min
3. Pressure head required 3 m
4. Assumed pumping efficiency 40%
5. Operating time 8,760 h/yr
6. Total dynamic head 3.3 m
7. Energy required 1,121 kWh/yr

Step 3: Grass Removal

1. Maintenance requirements, fuel use 0.59 MJ/harvest
2. Grass removal frequency 3 harvest/yr
3. Fuel for harvest (including transportation) 3.04 MJ/ha
4. Total fuel required 3.63 MJ/yr = 1.0 kWh

Step 4: Total energy use = 3,235 kWh/yr

8.6 Equations for Energy Requirements

In addition to Equation 8-1, a large number of equations have been developed from the curves in reference [6] and are presented in reference [5] . Selected equations are presented in this section to allow the engineer to estimate energy requirements for minimum preapplication treatment and for the three land treatment processes. In all equations, Y is the energy requirement in kWh/yr.

8.6.1 Preapplication Treatment

Mechanically Cleaned Screens

$$\log Y = 3.0803 + 0.1838(\log X) - 0.0467(\log X)^2 + 0.0428(\log X)^3 \quad (8\text{-}3)$$

where Y = electrical energy required, kWh/yr

X = flow, m^3/d (Mgal/d)

Assumptions = normal run times are 10 mm/h, bar spacing 1.9 cm (0.75 in.), worm gear drive is 50% efficient

Comminutors

$$\log Y = 3.6704 + 0.3493(\log X) + 0.0437(\log X)^2 + 0.0267(\log X)^3 \quad (8\text{-}4)$$

Grit Removal

$$Y = AX^{0.24} \quad (8\text{-}5)$$

A = 73.3(530)
X = flow, m^3/d (Mgal/d)

Assumptions = nonaerated, square tank, 2 h/d operation

Aerated Ponds

$$Y = AX^{1.00} \quad (8\text{-}6)$$

A = 68.7 (260,000)
X = flow, m^3/d (Mgal/d)

Assumptions = low speed mechanical aerators, 30 d detention, 1.1 kg 0_2/kWh

Other preapplication treatment processes will involve many potential sludge treatment and disposal options and are included in reference [5].

8.6.2 Land Treatment Processes

For sprinkler application in each land treatment process and OF and RI distribution, use the previous checklist and Equation 8-2. Equations are presented for ridge and furrow, and graded border SR application along with the assumptions.

Ridge and Furrow

Application = 250 d/yr, tailwater return at 25% annual leveling and ridge and furrow replacement

$$Y = AX^{1.00} \text{ - electrical} \quad (8\text{-}7)$$
$A = 3.17\ (12{,}000)$
X = flow, m^3/d (Mgal/d)

$$Y = AX^{1.00} \text{ - fuel} \quad (8\text{-}8)$$
Y = MJ/yr (10^6 Btu/yr)
$A = 1.55\ (20)$
X = flow, m^3/d (Mgal/d)

Graded border

Application = 250 d/yr, tailwater return at 25%

$$Y = AX^{1.00} \quad (8\text{-}9)$$
$A = 4.2\ (16{,}000)$
X = flow, m^3/d (Mgal/d)

8.7 References

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